Development of an Advanced Urban Dispersion Modeling Capability

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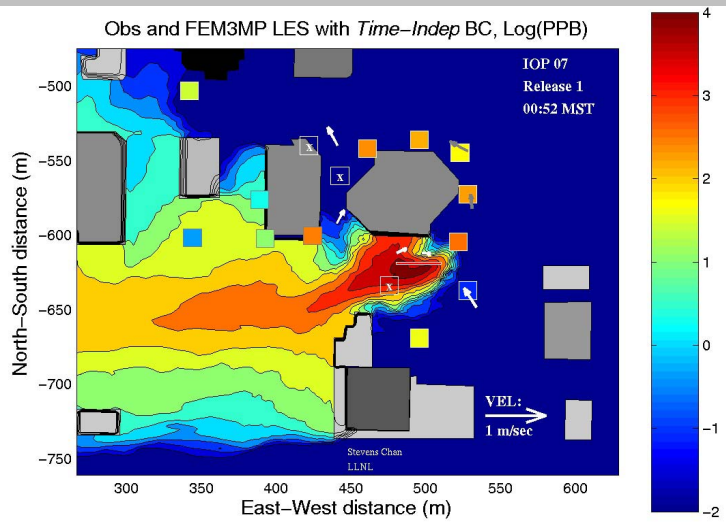
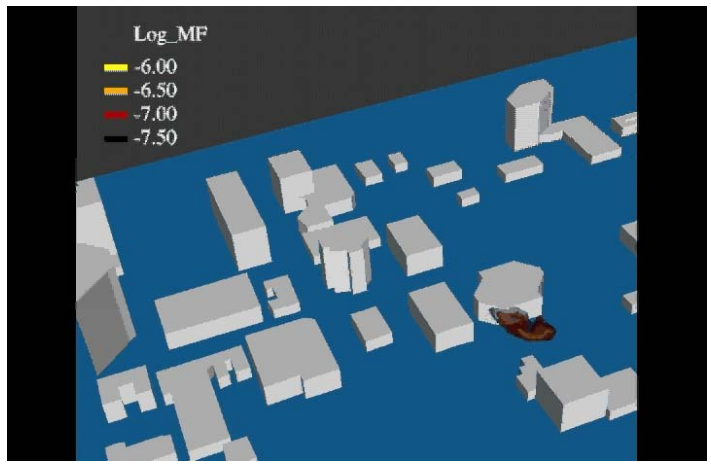
Accurate and timely prediction of atmospheric dispersion of hazardous materials is a critical national security need.

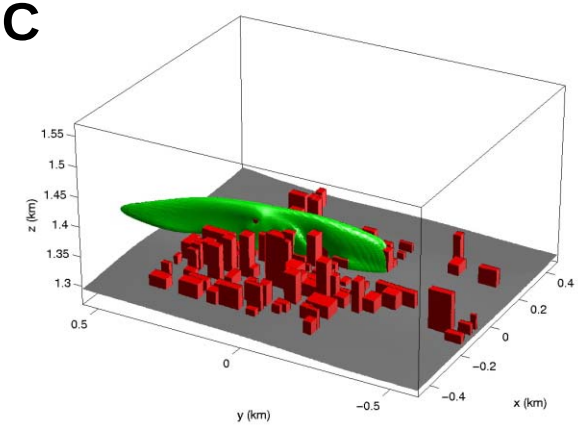
- **High-fidelity urban dispersion simulations are important:**
  - Experimental measurements alone are insufficient for emergency response and planning
  - Field experiments are expensive
  - Simulations are used to guide more effective sensor deployments
  - Together with measurements, simulations are an essential tool for event reconstruction



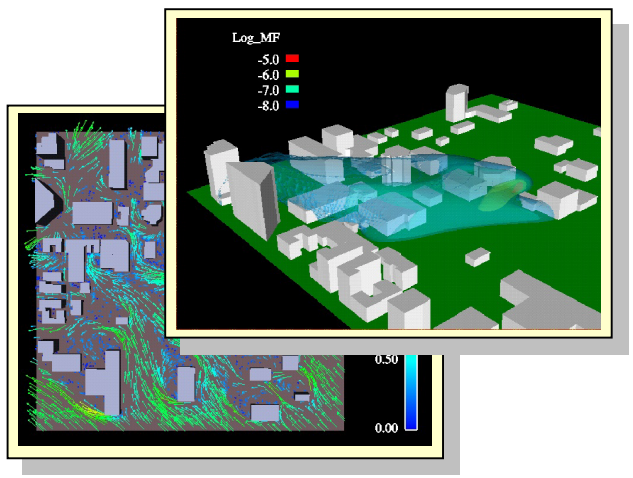


Urban dispersion modeling capabilities have been developed by researchers in NARAC

- **The standalone FEM3MP code is the primary urban dispersion modeling code used in the atmospheric sciences division in NARAC**
  - Finite element incompressible CFD
  - Structured mesh
  - LES & RANS turbulence models
  - Atmospheric chemistry

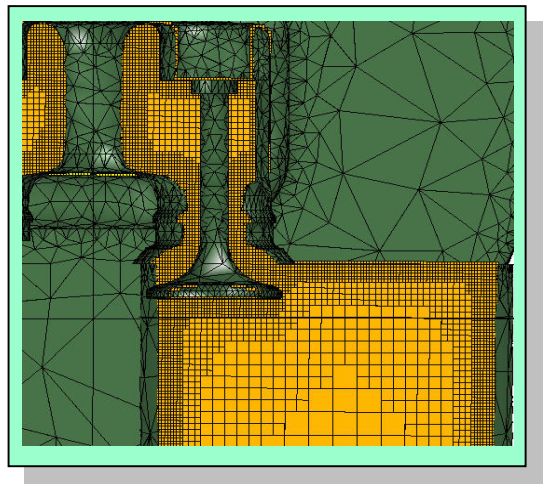


- **<u>Operational</u> use limited due to**
  - Simple geometry representation
  - Laborious grid generation
  - Range of release scenarios (e.g. unable to simulate moving sources)

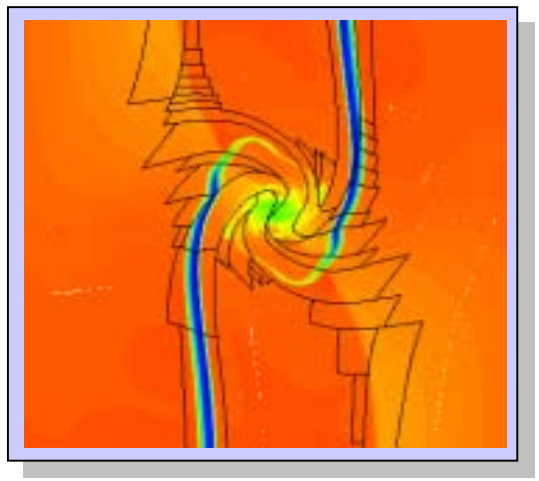


We propose to apply advanced meshing tools to the numerical models developed in NARAC

- **The Overture project has tools for rapid geometry-to-mesh (Rapsodi) capability**
  - Rapid construction of surface grids from CAD data
  - Interfaces to fast volume grid generator from NASA (CUBES)



- **The SAMRAI infrastructure supports a variety of parallel AMR applications**
  - Data structures for flexible mesh geometry
  - Adaptive mesh refinement
  - Scalability verified on > 1K processors



The coupled technologies will lead to an advanced operational capability

FEM3MP

Incompressible flow solver for urban dispersion applications

SAMRAI

Support for flexible mesh geometry: Adaptive mesh refinement

Overture

Rapid geometry-to mesh capability using building datasets

Next-generation State-of-the-art Integrated Urban Dispersion Capability

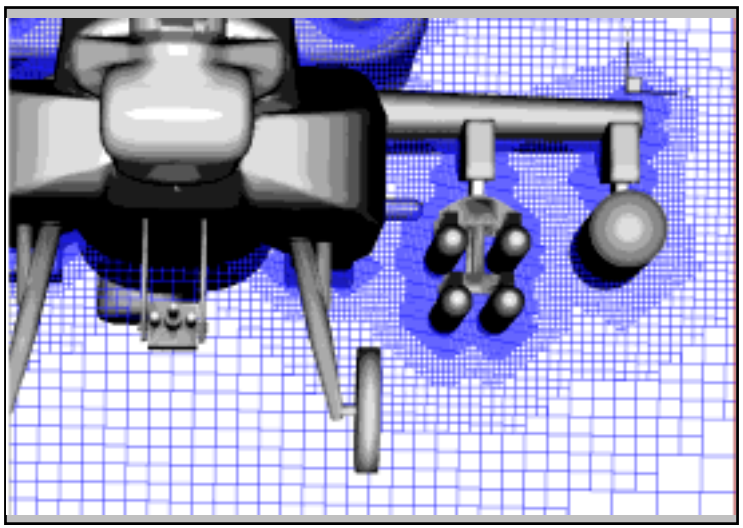
- **Automatic mesh construction from building datasets.**
- **Geometrically complex buildings and cityscapes**
- **Applicable to diverse urban environments:** stadiums, arenas, subways, etc.

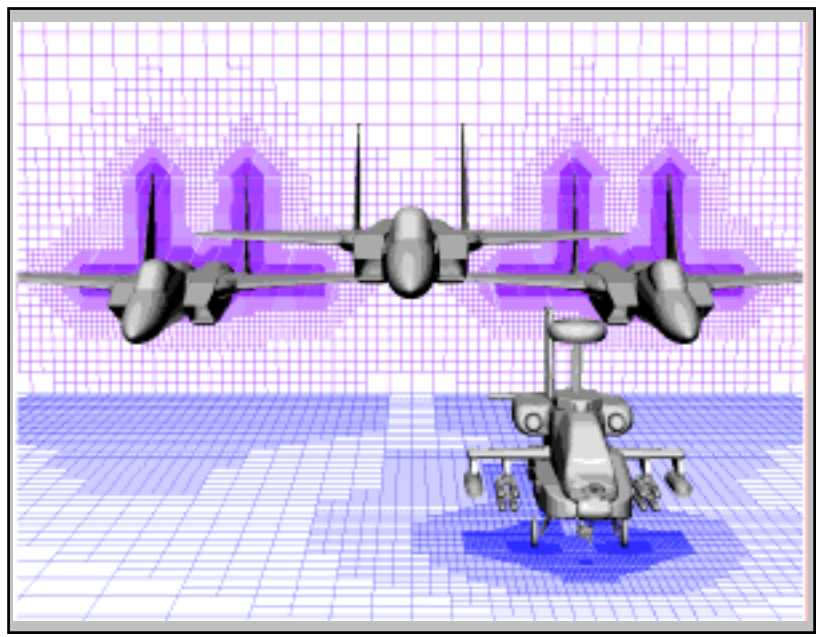
- **Adaptive mesh refinement capability**
- **Enhanced fidelity around important flow regions:** release source, building entrance, etc.
- **Complex release scenarios:** moving sources, etc.

The CUBES software is used to build adaptive cut-cell volume grids

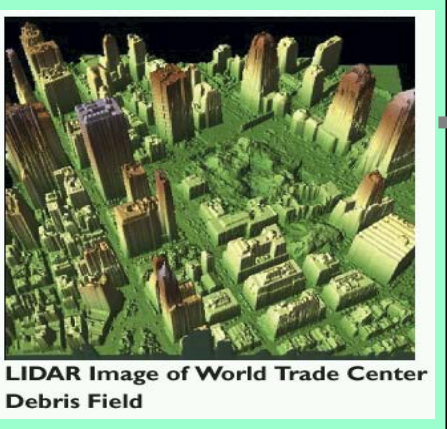
- **CUBES is a grid generator developed at NASA Ames for automated CFD analysis.**
  - Developed by Marsha Berger (NYU, Courant) and Mike Aftosmis (NASA Ames)
  - Readily handles complex geometries
  - Very fast

Example applications of CUBES – courtesy Berger, Aftosmis NASA Ames





An integrated set of tools will provide rapid geometry to solution capability

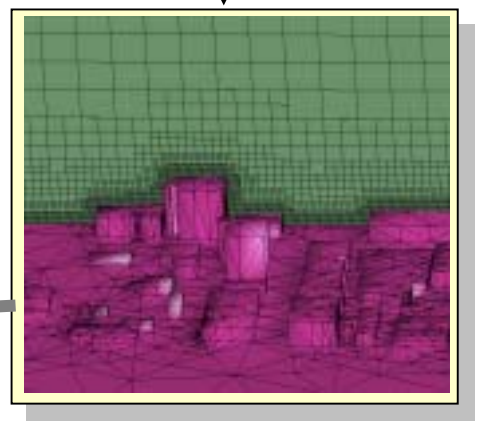


LIDAR Image of World Trade Center Debris Field

Geometry description

Overture (Rapsodi)
Surface grid generation

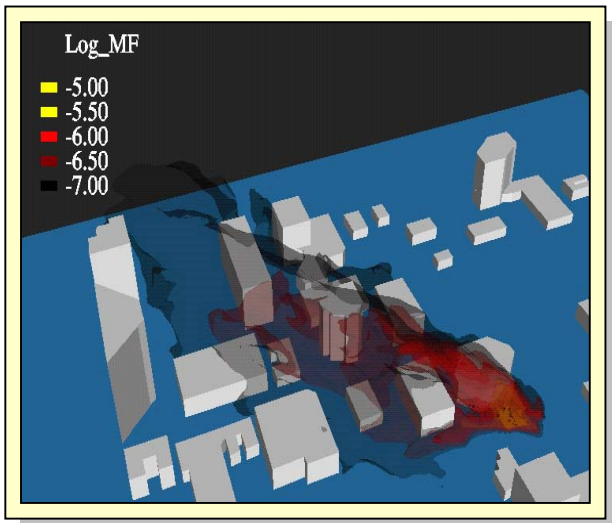
CUBES
Cut-cell grid generation



Adaptive cut-cell grid (downtown Salt Lake City)

FEM3MP
CFD & Dispersion Models

SAMRAI
Adaptive meshing, complex geom defn



Parallel Adaptive flow solution

Links exist

Developing links

Multidisciplinary Project Team

Technical team:

Kyle Chand (Overture, CASC)	grid generation	25%
Brian Gunney (SAMRAI, CASC)	AMR, numerical alg.	25%
Craig Kapfer (SAMRAI, CASC)	AMR, software integ.	50%
Branko Kosovic (FEM3MP, ASD)	atmospheric applic.	50%
Anders Petersson (Overture, CASC)	grid generation	25%
Andy Wissink (SAMRAI, CASC)	AMR, cut-cell grids	50%

Collaborator:

Marsha Berger (NYU, Courant)	grid generation	(unfunded)

Customers and Funding

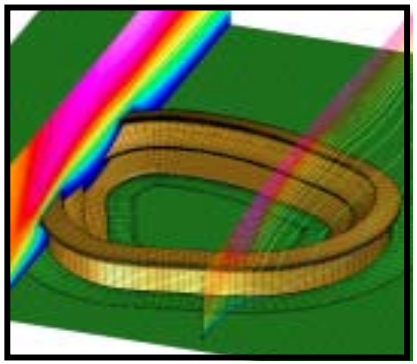
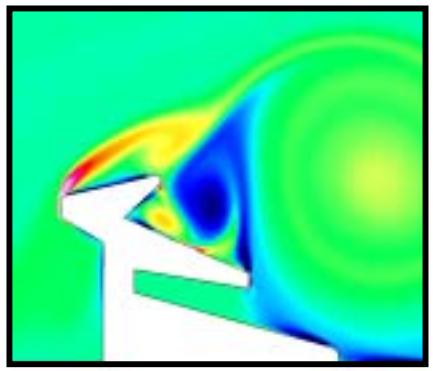
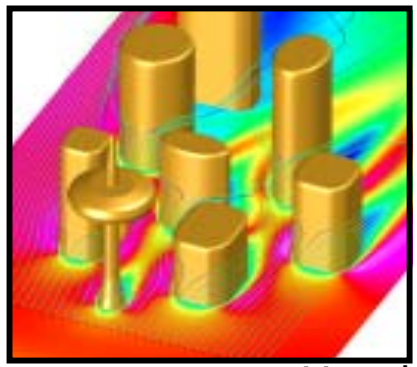
We are funded by the Threat Vulnerability Test and Assessment (TVTA) portfolio in the DHS S&T program.

National Release Advisory Center (NARAC) will be the primary customer

- NARAC is a part of the Emergency Preparedness and Response program in the DHS
- Infrastructure and critical facility protection, vulnerability studies

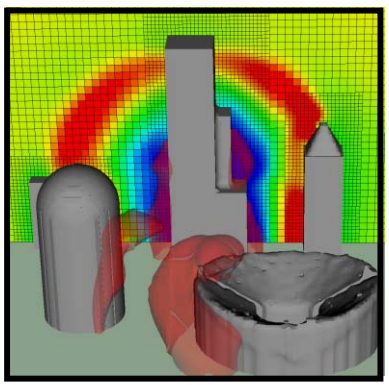
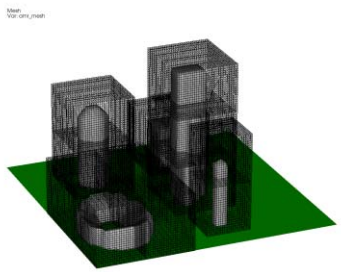
Demonstration calculations with prototype problems – 9/03

- **Flow around stadium and sample cityscape with overset grids**

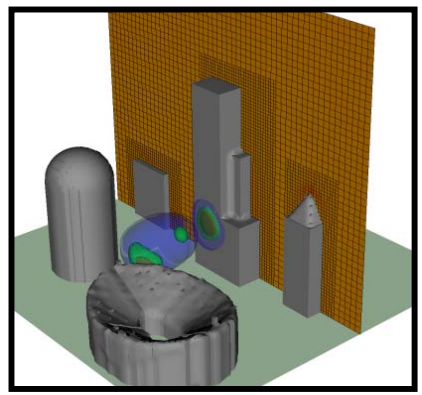




Henshaw 9/03

- **Adaptive flow simulation over prototype cityscape with cut-cell grids**

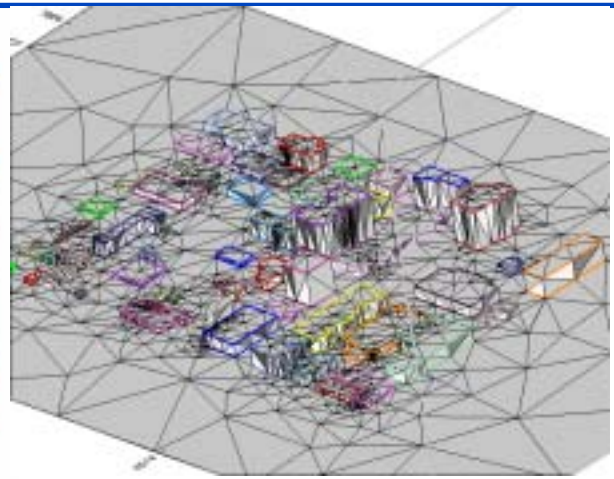



Refined region around buildings



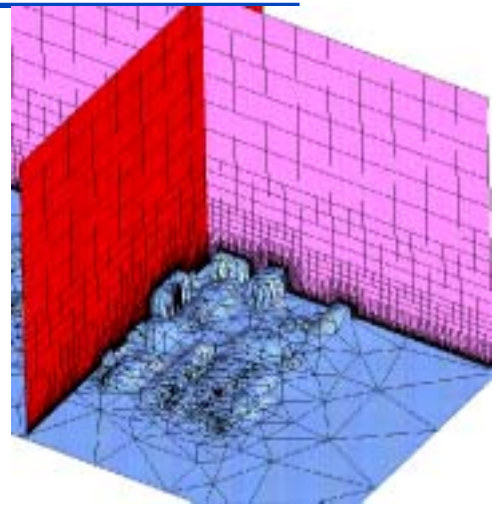
Automated cut-cell grid generation from building datasets – 1/04

Polygonal geometry data (Salt Lake City)



Chand 1/04

Surface triangulation by metro



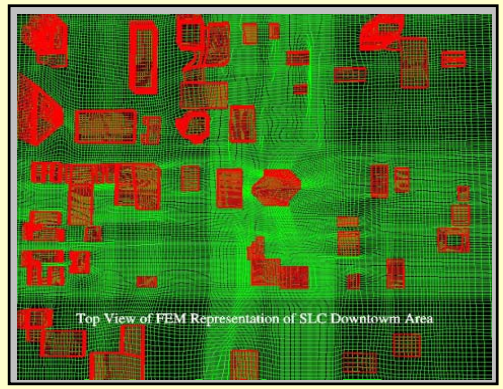
AMR volume mesh by CUBES

- **"metro" reads building geometry data and generates surface triangulation and CUBES input**
- **GUI interface that allows user to interactively add/modify/delete buildings**

Mesh generation with new tools is considerably faster than current tools

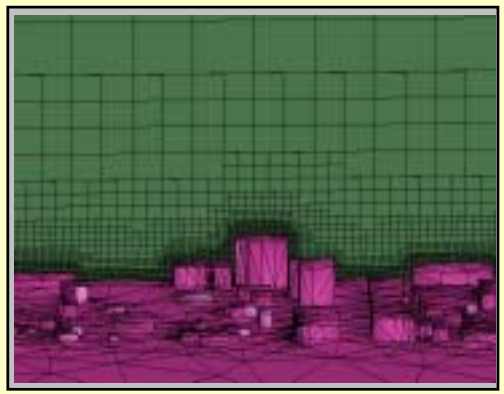
Downtown Salt Lake City

- **Structured conforming grid constructed with existing tools required about a <u>week</u>**



- **Adaptive cut-cell Cartesian grid generated with metro & CUBES required about <u>2 minutes</u>**

1.7M gridpoints, 6 levels refinement
Surface grid – 30 sec with “metro”
Volume grid – 45 sec with “CUBES”



Automated overlapping grid construction from building geometry information

Polygonal geometry data (Salt Lake City)

2D overlapping grid (ogen)

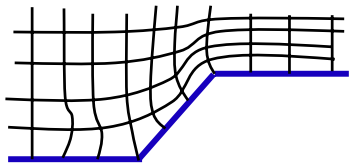
INS Solution (Overblown)

Henshaw 1/04

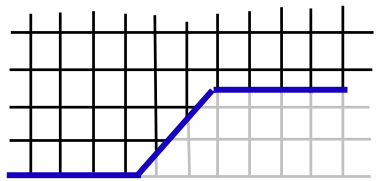
- **Body-fitted grids are automatically generated for each building**
- **Cartesian grid fills background and far-field**
- **Overlapping grid is automatically assembled**

Research issues still to be addressed in FY04

- **Finite element boundary representation on cut-cell grids – fictitious domain**



"conforming" mesh
(current)

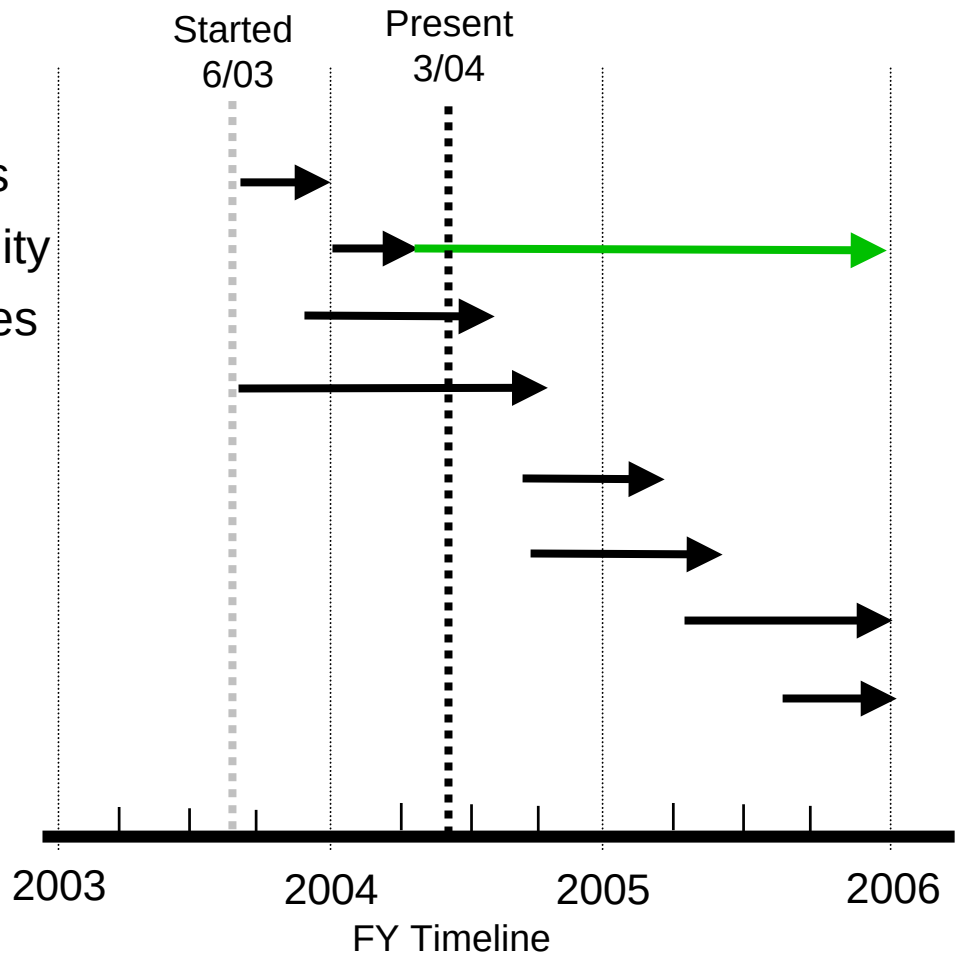


"cut-cell" mesh
(new)

- **Adaptive algorithms for Q1Q0 and Q1Q1 element incompressible CFD solver**
- **Building geometry information that incorporates new features**
  - **Standard formats adopted by DHS?**
  - **Incorporating terrain**

Project Tasks and Timeline

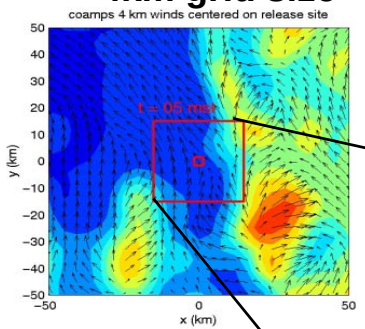
- Demonstration calc with prototypes
- Develop geometry to mesh capability
- Develop CUBES/SAMRAI interfaces
- SAMRAI-FEM3MP integration
- Develop cut-cell FE algs
- Develop AMR capability
- Validation, refinement studies
- Fine-tune the performance for operational use



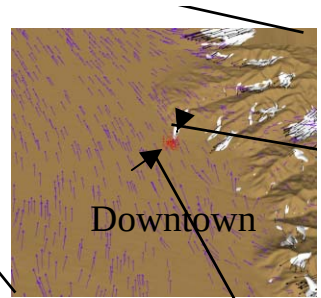
Potential Longer-term Research Challenges

- Coupling models with different scales
- Diverse urban environments – subways, arenas, etc.

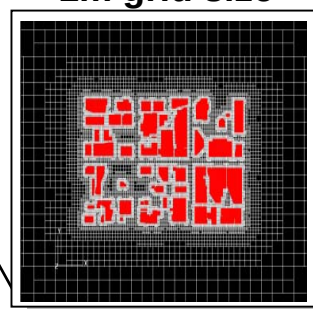
REGIONAL SCALE
4km grid size



MESOSCALE



URBAN SCALE
1m grid size



- Large-scale cityscapes (e.g. Manhattan)
- Performance on diverse parallel architectures

Conclusions

- **We are pursuing an advanced urban dispersion modeling tool by combining expertise in meshing technologies from CASC and NASA with atmospheric model expertise in NARAC.**
- **The tool will be used for emergency response, scenerio planning, and event reconstruction capability**
- **Our grid generation approach demonstrates it is possible to reduce meshing times from weeks to minutes.**
- **Anticipate fully adaptive tool to be available for operational use in NARAC by late 2005.**

Acknowledgments

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